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TITLE: SODIUM VAPOR HEAT PIPE LASER CELL

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Abstract

A sodium heat pipe cell containing high-voltage discharge plates was constructed to study the band absorption of light by the sodium dimer and to determine the feasibility of creating a metal vapor laser. Spectrographic measurements indicated that the increase in sodium dimer population with temperature resulted in 90% light absorption at 970 K. High-voltage discharges in the sodium vapor dissociated the dimers and restored transparency to the medium. No lasing action of the sodium vapor with high-voltage discharges was observed either because of insufficient ionization or nonuniformity of the ionization over the plate area.

Introduction

To produce laser beams with various specific wavelengths, there has been a growing interest in the possibility of using metal vapor atmospheres. Such applications require containment of high-temperature vapors in horizontal tubes with windows at each end and feed-throughs for a high-voltage plate system to ionize the metal atoms. High saturation temperatures of the vapor are required to produce sufficient atom density for efficient laser operation. As there are no satisfactory high-temperature seals available, high-voltage feed-throughs and windows must be kept in relatively cool zones compared to the temperatures required in the metal vapor zone. However, this introduces the problem of vapor migration with condensation occurring at the cooler regions, resulting in metal coatings forming on the windows and insulators.

One method for blocking the vapor flow to the cooler regions is to construct the cell as a gas-controlled heat pipe with an inert buffer-gas zone at each end to limit the axial vapor flow and maintain cool zones at the ends of the cell (see Fig. 1). The saturation temperature of the vapor can be established by controlling the buffer gas pressure and the location of the gas interface varied by adjusting the power input to the evaporator heater.[1]

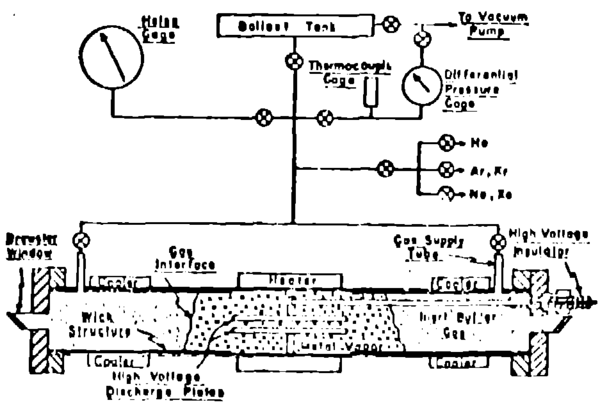

Fig. 1 Metal vapor laser cell.

When the power is increased or decreased, the interface will move axially to provide more or less condenser area as required to maintain the saturation temperature. For proper laser operation, the interface would have to be relatively vertical and stable to prevent diffusion or scattering of the beam. In horizontal cells this is difficult to achieve because of convection and gravity effects which result in sloping interfaces and unstable conditions.

To study the operational characteristics of this type of system, a heat pipe 7.62 cm in diam and 91.4 cm long was constructed and tested with both water and mercury as the working fluids. It contained no high-voltage plates or feed-throughs and had 5 cm-diam flat windows in place of Brewster windows. The main objectives of the tests were to determine the effect of heat pipe diameter, buffer-gas density, and convection on the stability of the interface. This system was operated successfully with a relatively vertical gas interface and the windows remained clear over long periods of time.[2]

Sodium Vapor Cell

A second system was constructed for operation with sodium vapor. This cell was 10.2 cm in diam and 93.4 cm long with an annular sodium heat-pipe oven at the center section to provide for an isothermal heat input to the cell as shown in Fig. 2. Each heat pipe had its own gas-control system for separate control-gas pressure (see Fig. 3).

It has been reported that sodium vapor absorbs particular wavelengths varying from red to violet with increasing temperature and eventually becomes opaque to the visible spectrum.[3] This occurs because of the presence of the sodium molecule or dimer which results in band absorption. As the temperature is increased, the dimer population increases resulting in more band absorption. Such absorption would be detrimental to the transmission of a laser beam so the experiment was divided into two parts. The first part was to operate the cell with no high-voltage plate system installed and run a series of tests over a temperature range with three different inert gases - argon, helium, and neon. A white light from a tungsten-halide lamp was focused with a lens and directed through the sodium vapor in the cell to a recording spectrograph so that the absorption as a function of wavelength could be determined. The second part of the experiment was to install a high-voltage plate system in the cell to determine if high-voltage discharges dissociate sodium dimers sufficiently to restore transparency to the medium and also if the discharges would produce a sodium laser beam.

Light Absorption Tests

The tests to determine the absorption of light by sodium vapor verified that absorption increases with temperature. Measurements of the intensity of the light transmitted were made by the spectrograph

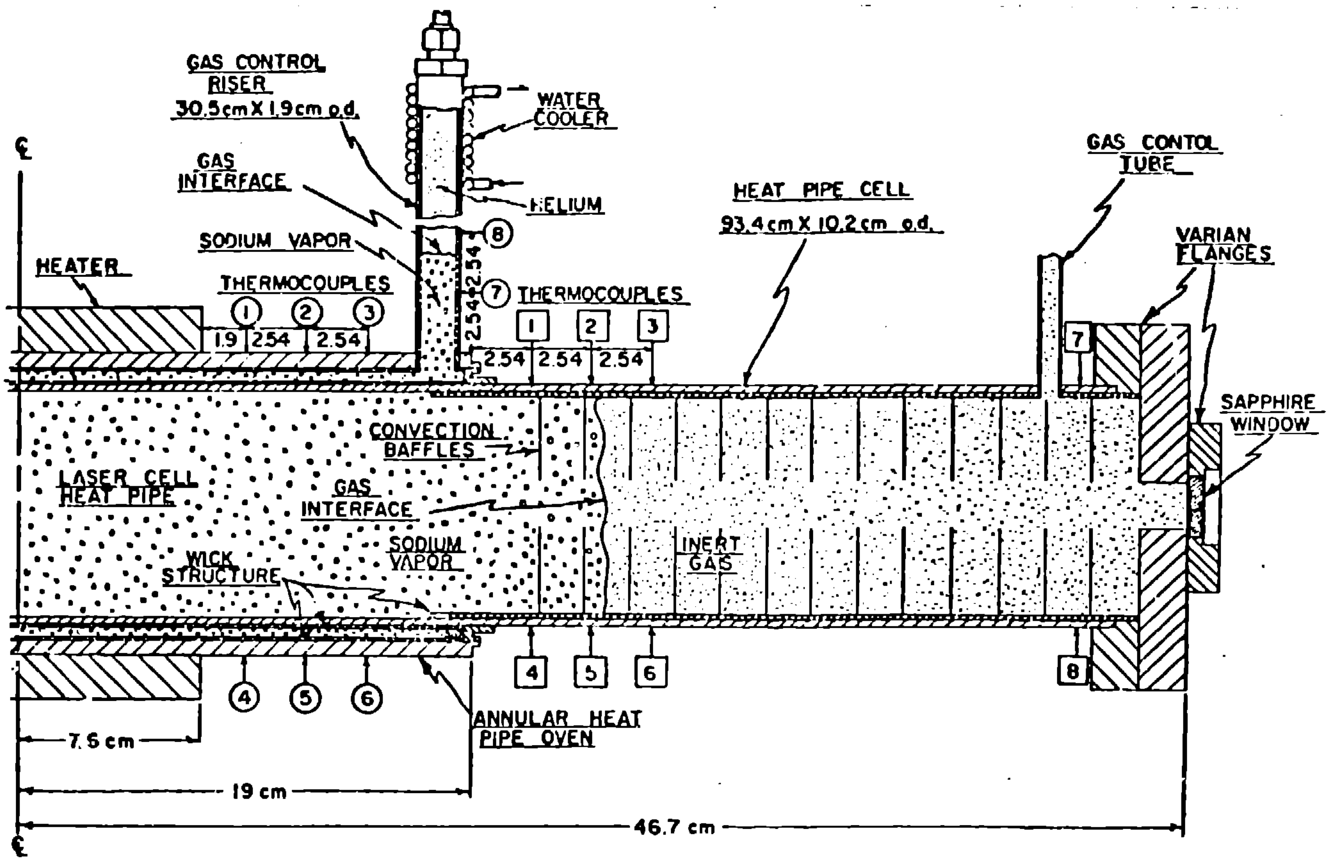

Fig. 2 Test cell for light absorption studies.

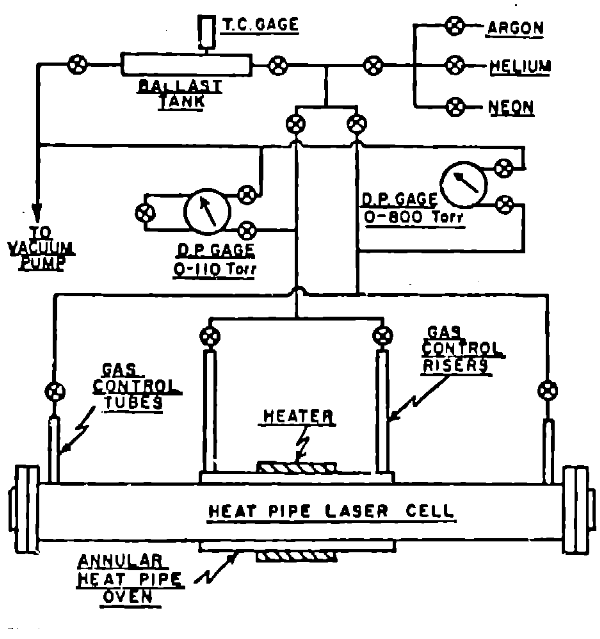

Fig. 3 Gas-control system.

over a spectrum range of 3200 to 7700 Å. Visual observations also verified the change in absorption wavelength by color changes in the cell from white to yellowish-green, dark green, blue, and finally violet at the highest operating temperature. The results of the tests are summarized by the curves shown in Fig. 4. This figure also shows the approximate wavelengths of the various color ranges. The curves show the change in intensity of a beam of white light passing through a sodium atmosphere at different heat pipe oven temperatures as recorded by the spectrograph with a helium buffer gas in the cell.

Curve A was obtained from a run made at room temperature with three different gases - argon, helium, and neon. The gas pressure was varied from 1 atm to vacuum with each gas but there was no change in the intensity of the light transmission through the cell and the type of gas or pressure had no effect. The normal black body curve for the tungsten-halide lamp peaked at about 10,000 Å, however, the curve obtained was cut off well below this value because of the spectral response of the photomultiplier and spectrometer.

Curve B was obtained for an average heat pipe oven temperature of 700 K. Line absorption by the sodium atom reduced the intensity at 5893 Å to almost zero. Between 4700 and 4200 Å molecular or band absorption started to appear as shown by the irregular wave pattern and a large decrease in intensity. There was also a reduction in the main peak of the curve. The light in the cell was a yellowish-green color.

When the heat pipe oven temperature was increased to 790 K (curve C), complete absorption resulted down to 5800 Å. There was transmission between 5800 and 5200 Å resulting in a darker green light emerging from the cell with the main peak intensity reduced by 50%. The band absorption

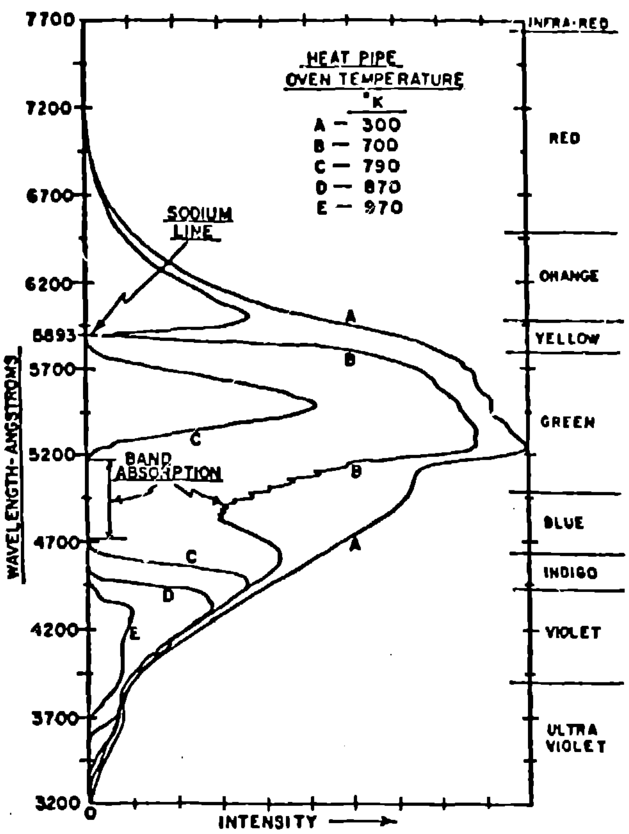

Fig. 4 Light absorption by sodium vapor.

between 5200 and 4700 Å reduced the intensity to zero. Below this wavelength transmission again occurred beyond the visible range.

Curve D was obtained with an oven temperature of 870 K. Complete absorption occurred down to a wavelength of 4500 Å changing the color of the emerging light to indigo. A series of runs was also made at this temperature with neon as the buffer gas and the pressure varied from one atmosphere down to one-half an atmosphere but there was no change in the spectrographic curves. This indicated that the absorption of light was a function only of the pressure and temperature of the sodium vapor and was independent of the type or pressure of the buffer gas.

When the oven temperature was increased to 970 K, complete absorption occurred down to 4450 Å (curve E). There was some transmission between 4450 and 3700 Å but the intensity was only 10% of the original peak intensity and the emerging light was a deep violet color.

At the end of the test series, a scan was made with both a vacuum and one atmosphere of helium in the cell at room temperature. The original spectrographic curve was duplicated, indicating that the buffer gas at the ends of the pipe prevented any sodium condensation on the windows.

High Voltage Discharge Tests

Upon completion of the light absorption tests, the sodium was distilled out of the cell and the wick structure replaced. Before installing the high-voltage plate system, a small cell was constructed to test the compatability of insulator materials with sodium liquid and vapor and to study glow discharges in sodium vapor. This cell was 3.8 cm o.d. and had a T-connection at one end for the introduction of a high-voltage lead to a spark-gap and provide for a sapphire window to observe the effect of high-voltage discharges on sodium dimers. A superheater was placed around the spark-gap area and saturation heaters covered the ends of the two wick structures as shown in Fig. 5. Neon buffer-gas zones were maintained and controlled through tubes at each end of the cell connected to a gas supply and a vacuum system. Both alumina and boron nitride insulators were subjected to sodium liquid and vapor at 873 K. These materials were readily wetted by sodium, but there was no evidence of attack or disintegration. After the cell was wet in, a voltage test was made at room temperature with a vacuum in the cell and the insulator system withstood 20 kV without a voltage breakdown. When a white light was beamed into the cell at an operating temperature of 873 K, the reflected light appeared dark green in color because of the molecular or band absorption by the sodium vapor. However, when a high voltage was applied, a glow discharge was obtained in the spark gap which emitted a characteristic yellow sodium D line. The observation of this wavelength indicated there was dissociation of the dimers which decreased absorption of light by the sodium vapor. This also demonstrated that sodium ionizes readily and that a glow discharge could be obtained without a preionizer. The only difficulty encountered in the operation of this cell at temperature was that the high-voltage lead acted as a cold finger resulting in the formation of liquid drops on its surface in the vapor zone. These drops would eventually become large enough to cause arcing to the wetted insulator surrounding the spark gap. From these tests it was evident that the high-voltage lead would have to be superheated to prevent any condensate from forming.

A high-voltage plate system was then constructed and installed in the large cell as shown in Fig. 6. The plates were 25 cm long by 2.5 cm wide and supported in a boron nitride insulator with a gap spacing of 1 cm. The high-voltage lead was a 1 cm diam tube inserted through a teflon-insulator seal mounted in the end flange and insulated with an alumina tube from the teflon insulator to the plate connection where it was covered with a boron nitride enclosure. A ceramic heater was designed which could be inserted inside the tube to superheat the area where it connected to the high-voltage plate.

After the cell was loaded with 90 g of sodium and the wick structure wet in a series of tests was made at various temperatures to determine if a sodium laser beam could be obtained with high-voltage discharges in a sodium atmosphere. An optical resonant cavity using broad band mirrors was set up so that if a sodium laser beam was emitted from the cell it could be observed on an image screen. The system was aligned by an external laser beam through a beam-splitter and focused on the image screen. (see Fig. 7). This beam was shut off when tests were made to determine if the cell emitted a sodium laser. A helium-cadmium laser was used for the alignment as it emitted a blue light at 4416 Å which could pass through the sodium atmosphere without being absorbed. High-voltage pulse discharges produced a yellow glow discharge

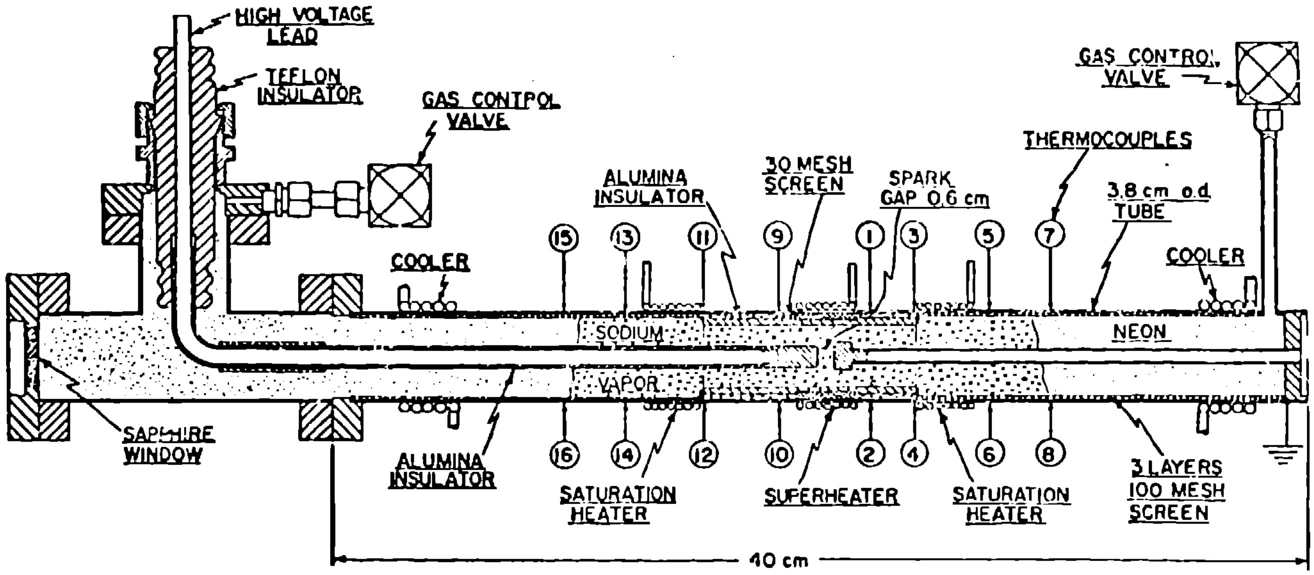

Fig. 5 Insulator compatability test cell.

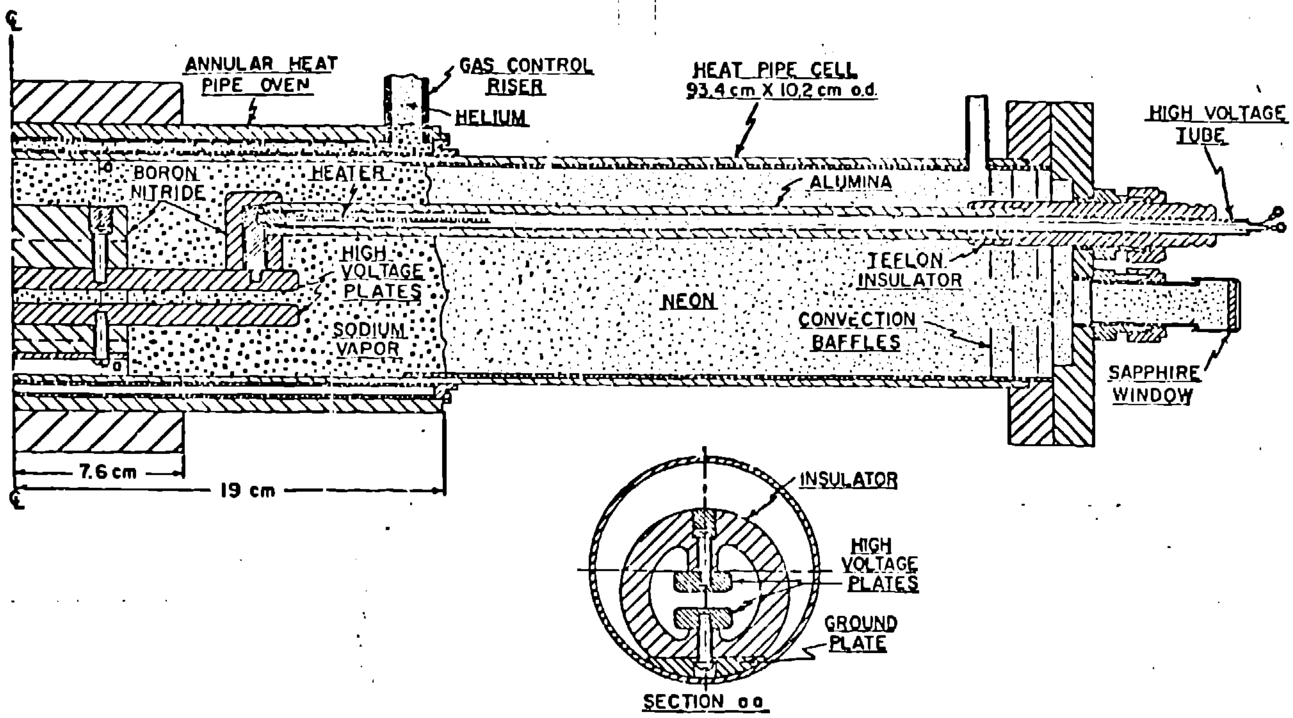

Fig. 6 Sodium heat pipe cell with high-voltage plate system.

with currents up to 65 amp across the plates, but no sodium laser beam was emitted from the cell. The inert-gas buffer zones at the end of the cell kept the windows clear of sodium condensate, however, the teflon feed-through for the high-voltage lead eventually broke down resulting in a short to ground. During this test the discharge zone was kept superheated at 873 K or above, to prevent any condensate from forming on the plates, with sodium saturation temperatures up to 793 K as determined by the temperature at the ends of the wick structures. It was estimated that at the saturation temperature the sodium atmosphere had a density of 5×10^{15} atoms/cc.

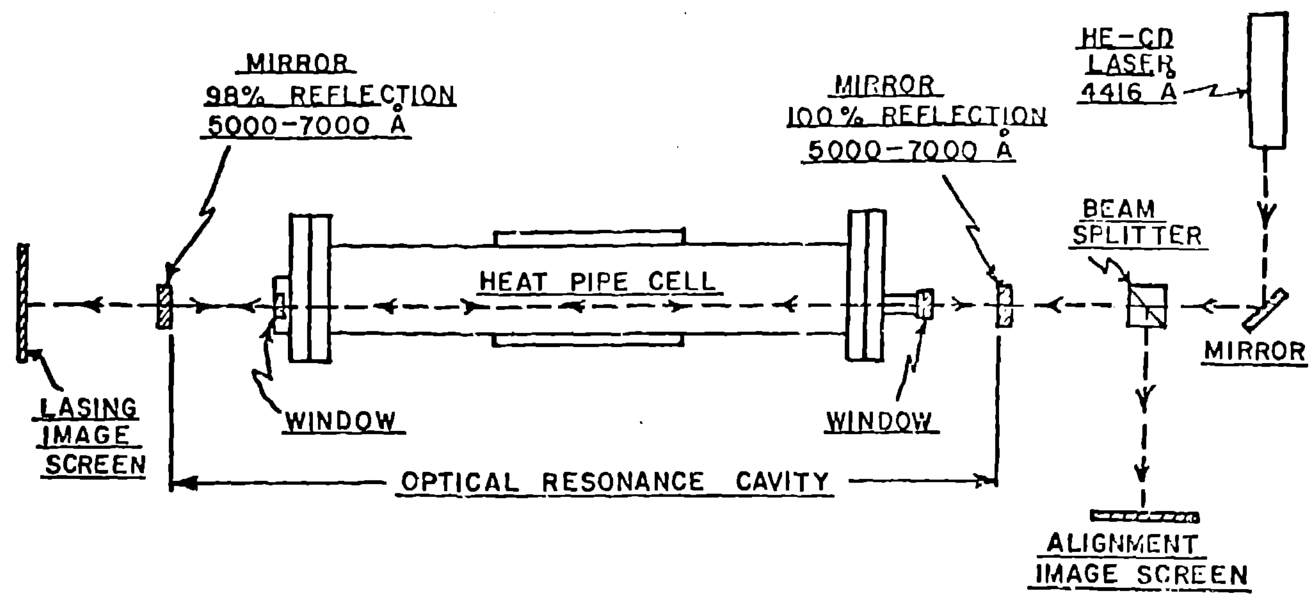

Fig. 7 Optical system for Lasing test.

Conclusions

Light Absorption Tests

From these tests it is apparent that the increase in sodium dimer population, that occurs with increasing temperature and vapor pressure, eventually results in a high degree of opacity to light transmission by the sodium vapor. The rate of transmission decrease indicated that absorption in the visible region of the spectrum would be essentially complete at a temperature slightly above 973 K.

High Voltage Discharge Tests

The results of the tests with high-voltage glow discharges in a sodium atmosphere indicated that the discharges resulted in dissociation of the sodium dimers and restored transparency to the medium allowing passage of light in the visible range of the spectrum. No lasing action of the sodium was observed which may have been due to insufficient ionization or non-uniformity of the ionization over the plate area. Another reason for failure to obtain a laser beam may have been the fact that flat windows were used instead of Brewster windows which introduced an amplication loss of 8% per window. The project was terminated before any gain measurements could be made to determine if there was any amplification of a laser beam passing through the sodium atmosphere when subjected to high-voltage discharges.

During all the tests, the windows were kept clear of condensate by the buffer gas zones and the heat pipe wicking action maintained a sodium atmosphere. If further investigation of metal vapors is done for laser application, it is believed that a heat pipe cell is the only method available for maintaining a high-temperature metal-vapor atmosphere while keeping windows and feed-throughs clear of condensate in cooler zones.

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Acknowledgment

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